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DEPARTMENT OF

SPACE PHYSICS AND ASTRONOMY

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FINAL REPORT ON

SCIENTIST/AMPS EQUIPMENT INTERFACE STUDY

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DEPARTMENT OF SPACE PHYSICS AND ASTRONOMY

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INTRODUCTION

This report was prepared under Contract NAS8-31679 "Scientist/AMPS Equipment Interface Study". A committee of faculty agreed to study this interface for eleven experiments that might be performed on AMPS. The experiments wre selected by a subcommittee of the AMPS Scientific Definition Working Group.

Objectives

The principal objective is to determine for each experiment how the operating procedures and modes of equipment onboard Shuttle can be managed in real-time or near-real-time to enhance the quality of results. As part of this determination we have defined the data and display devices that a man will need for real-time management.

The secondary objectives, as listed in the RFQ and technical proposal, are to

- determine what quantities are to be measured
- determine permissible background levels
- decide in what portions of space measurements are to be made
- estimate bit rates
- establish time-lines for operating the experiments on a mission or set of missions
- determine the minimum set of hardware needed for real-time display

Approach

After preliminary discussions the committee, which consisted of Anderson, Casserly, Chamberlain, Cloutier, Freeman, Stebbings, and Wolf, agreed to accept individual assignments to write up experiment descriptions and requirements. These are presented in section two under the authors' names. Harry Koons, of Aerospace Corporation, provided descriptions of the wave experiments under subcontract to Rice.

The Principal Investigator then wrote the other parts of this report, combining the requirements of the various experiments and defining a minimal set of joint requirements. The results were reviewed by other members of the committee at Rice.

Comments

It should be noted that the descriptions of experiments contained in the IFRD and EOR documents are extremely sketchy in some cases. We have had to define particular experiments that fit under the titles we were given. Describing every possible experiment that might be covered under the titles would have been beyond the scope of this study.

We have addressed ourselves to the control and management of apparatus in real-time and near-real-time, not to its repair. Hence, given sufficient two way telemetry from Shuttle to mission control on the ground, all display and analysis of data and control of apparatus could be conducted by a science team on the ground. However, the P.I. and most of the other committee members, tend to think of the real-time work being carried out by payload and mission specialists aboard the orbiter.

Experiments Studied

Table I.

Number	Experiment	Assigned to:
I	Auroral input-output	Anderson
II	Electron-echo and $E_{\parallel}$	Casserly & Wolf
III	Flow dynamics around a test body	Cloutier
IV	Acoustic gravity waves	Cloutier
V	Plasma seeding experiment	Wolf
VI	Metallic chemistry	Stebbings & Chamberlain
VII	Measurement of trace species	Stebbings & Chamberlain
VIII	Chemical & dynamic studies using gas releases	Freeman
IX	ELF/VLF antenna development	Koons
X	Beam excitation of plasma waves	Koons
XI	HF wave/particle interaction	Koons

Some instruments that are referred to frequently in the text are listed below in Table I. Data rates are, in most cases, only approximate.

Table II.

Frequently referenced detectors.

(Older, 1975, numbers in parenthesis)

Particle detectors

IFRD #		Name	Data rates, kb/sec, unless stated otherwise: current	(old numbers)
		On Shuttle		
III-6	(49)	Energetic ions, 20 MeV-10 MeV	52.3	(800)
-7	(50)	Med. energy electrons, 10 eV-50 keV	256	(512)
-9	(51)	Med. energy ions, 10 eV-50 MeV	10 MHz	(250)
-10	(52)	Ion mass district,thermal, 1-64 AMU	72	(72)
-11	(53)	Energetic electrons, 15 keV-3 MeV	10 chan, 5 MHz	(100)
-12	(54)	Med. energy ion mass analyzers, 10 eV-50 keV	23	(23)
-20	(48)	Energetic ion mass analyzer, 25 keV-10 MeV	6 plus 3 chan, 1 MHz	(6)
		Total in kilobits/sec (older bit rate used where not available in newer version.)	759.3	(1763)
		On Subsatellite		
III-8		Med. energy electr., 10 eV-50 KeV	32	
-13	(57)	Energetic ions, 20 KeV-10 MeV	20	(1)
-14	(58)	Energetic electr., 15 keV-15 MeV	1	(1)
-15	(59)	Med. energy ions, 10 eV-30 keV	25.6	(25.6)
-16	(60)	Ion mass distrib., thermal, 1-64 AMU	2.4	(25)
-24	(56)	Energetic ion mass analyzer, 25 keV-10 MeV	0.8	(0.8)
		Total in kilobits/sec	81.8	53.4

III-1	Ion drift	4.8
-2	Vector magnetometer (also on subsatellite)	.96 or 300 kHz
-3	Level 1 beam diagnostics	3
-4	Level 2 beam diagnostics	3 x 100 kHz
-5	Level 3 beam diagnostics	1 - 100 MHz 2 - 10 MHz 2 - 100 kHz

Table II. Cont'd.

III-1	Ion drift	24.8
-2	Vector magnetometer	.96 or 300 kHz
-21	DC electric field	2
I-16A	ELF-VLF receiver	100 Hz-40 kHz
B	Electric dipole antenna	
C	Magnetic dipole antennas	

I. Auroral Input-Output Experiment

A. Purpose

The objective of these measurements is to increase the detailed understanding of the mechanisms that convert energy carried into the atmosphere by super thermal electrons and ions to the form of emitted photons, excitation and heat. Electrons or ions are to be fired from accelerators on Shuttle orbiter down the magnetic field with energies in the auroral range 1-10 keV and at various pitch angles. Emissions from orbiter altitude down to ∿ 100 km will be observed from the orbiter and from selected ground stations. Backscattered particles may be measured at Orbiter. It is possible that other ionospheric effects can be observed by Thomson scatter radars such as Chatanika and Arecibo.

This technique has the advantage over observation of the natural aurora that the input is a "delta function" in time so the temporal response of the ionosphere to such an input can be observed. Beam parameters can be varied at will and a range of latitudes will be covered. Some disadvantages are that the emission can be viewed from Orbiter only along the magnetic field so that no height profile can be obtained. Ground station instruments can obtain a height profile but must slew rapidly to keep up with the illuminated spot.

B. Data collection onboard Orbiter

1. The quantities to be measured are:

- The photon flux as a function of wavelength or at selected wavelengths covering near IR, visible and UV.
- The morphology of the emitting region as seen by an imager.
- Backscattered particle flux.

The latter is not essential for the emission measurements, and is really a different experiment.

The first measurement requires either photometers with selectable filters or a scanning spectrograph. Early flights will probably use the former. Such instruments are described by IFRD II-2,3,4.

A suitable imager is described by IFRD II-3.

A particle energy spectrometer to cover the range ∿ 0.01 to 10 KeV and mounted on a subsatellite will be required to detect backscattered particles. See IFRD III-8,15.

A particle accelerator producing ∿ 10 kw of beam with particle energy 1-10 KeV is needed.

a) Dynamic range and precision —

Photometer 10^5 range; 3% precision

Imager 10^5 range; the spot will be ∿ 0.100 km in diameter and must be resolvable from 100-200 km above (200-300 km altitude). This is .06° - .12°, which is compatible with a 200 line raster and 24° to 12° field of view..

Particle Detectors 10^5 range; 3% precision

b) Background-Night airglow, starlight, and weak diffuse aurora (IBC-I giving 1 kr of 5577) are acceptable. Bright aurora and moonlight are not. A 10 kw beam spread over 100 meter diameter spot will produce emission intensity about 500 times these levels. The photometers and imager should, however, have an instrumental background well below the natural one, perhaps 20 times lower, so that the range of 10^5 is reasonable.

For the particle detectors the natural background outside the aurora is acceptable. A flux of 10^5 elect/cm^2 sec and 10^3 ion/cm^2 sec are factors of ∿ 10^5 below a 10% return from a 10 kw beam.

2. Location

Measurements are to be made at all available latitudes, and are possible only when the Orbiter is in darkness and viewing dark Earth. Measurements may be attempted in the auroral zone but initially will be most successful at lower latitudes.

a) Consequently on a single orbit each run can be only $\leq$ 30 minutes for a 57° inclination.

b) Initially the more attempts the better. A reasonable program would be to make the measurement on 4 successive orbits each day of the mission, or if that is not possible every other day of the mission to allow time for observers on Orbiter and on the ground to digest the results. Desired running time is therefore 4 x 7 x 30 = 840 minutes in a mission.

The initial purpose of making several runs will be just to detect a signal. Once this is achieved, variations in atmospheric composition will be observed.

c) Data rates

Imager - 4 mHz bandwidth

Photometer - 5 bit precision, 4 to 5 bit dynamic range

Readout 100 times/sec = 10^3 bits/sec
for each photometer. (OBIPS writeup gives
1000 readouts/sec and ∿ 16 kbps.)

Housekeeping - .04 kbps

Input from orbiter of time, attitude, position - 11.4 kbps.

Total rate 4 mHz video
27.4 kbps

In 840 minutes = 5.04×10^4 sec one gets 1.38×10^6 k bits plus the video.

Particle detectors on subsatellite

Many different designs are possible. Using a scheme similar to IFRD III-8 with ten angle channels, 32 energy steps 10 eV-50 keV, 12 bit words and 100 samples per second, one gets 12 kbps and a complete energy scan 3 times/sec. IFRD III-8 gives 32 kbps.

Ion detector, IFRD III-15 gives 25.6 kbps.

Housekeeping, including attitude 6.6 kbps.

Location of subsatellite is a separate input.

One could scan a restricted energy range on command to increase the temporal resolution.

3. Conducting runs

a) Parameters to be varied

accelerator	—	type of particle accelerating voltage current pitch angle of injection beam pulse program
imager	—	focal length and field of view f stop gain and contrast integration time pointing direction filter-wavelength
photometer	—	focal length and field of view gain filter-wavelength pointing direction
particle detectors	—	adjust position of subsatellite program energy of spectrometer

b) Preprogramming

The pointing directions for accelerator and optical detectors should be preprogrammed as a function of the Orbiter's position using a model of the Earth's field. The pulse programs for the accelerator

must be automated so that one or another is selectable easily. Cross correlation with variable lag between the beam pulsing and the photometer output must be possible. Other functions must be pre-planned but not necessarily automated.

c) The following narrative account of a run will indicate which data are useful in real time and what can be usefully adjusted.

Prior to entering darkness adjust altitude of Orbiter and pointing angles of accelerator and optical detectors so that the latter views the foot of the B field line passing through orbiter. Pick a photometer filter covering the prompt emission to which photometer is most sensitive (λ4278). As darkness is entered start with low beam power and long pulse program. If the spot appears in the imager output, center the photometer on the spot. Using correlation program calculate and display intensity. (Raw data may be recorded or telemetered.) Offset photometer from spot $\perp$ to orbiter velocity to measure background. Then offset photometer behind spot to measure decay of emission after the beam passes. Step through wavelength filters, vary accelerating potential, current, etc.

If spot is not visible increase beam power until it becomes so. If no spot is seen by imager at maximum beam power then scan photometers (which are presumably more sensitive) about predicted position of spot using the output of the correlation program to decide when emission is being detected.

In the event that backscattered particles are being observed by detectors on a subsatellite the following sequence would be used:

precalculate the most probable location behind orbiter for backscattered particles to be detected along the orbital segment of interest;

position the satellite;

command the particle detectors to proper mode;

when the accelerator is operated look for enhanced spectrum;

if no backscattered particles are observed, increase the accelerator current;

cross correlate particle detectors and beam pulses with variable lag; vary lag and look for backscattering particles. Vary beam's pulse program;

if no particle identification is made, change separation of orbiter and subsatellite to try again on the next pass.

4. Real Time Display

a) Alphanumeric display of housekeeping and status

b) Video monitor showing scene viewed by imager. This should have a mark showing where the photometer or spectrograph is pointed. If these are bore-sighted with the imager this is easy. Otherwise the mark must be computer generated.

c) Mark on monitor screen showing the point where the local field line intercepts $\sim$ 100 km altitude level. This must be computer generated using the Orbiter Guidance and Navigation system output and a model of the geomagnetic field.

d) CRT display of orbiter-subsatellite geometry, or an alphanumeric display of position.

e) CRT display of energy or pitch-angle spectra of particles detected by subsatellite. Either background or correlated spectra should be selectable.

5. Computation required

a) Using G and N (Guidance, Navigation and Time) from orbiter and model geomagnetic field calculate location of field line for display on video monitor screen and for aiming accelerator.

b) If photometers are separate from imager, calculate the point at which they are aimed for display on monitor.

c) Take bit stream from particle detectors and convert to spectral display on CRT.

d) Correlate particle detector or photometer output with beam pulses. Gate accumulators with beam pulses, including selectable delay, so that the detector output when beam is on (with delay) is separated from the output when it is off.

6. Comment

See comments on Experiment II'.

II. E Parallel to B Experiment

A. Purpose

The objective of this experiment is to determine whether or not electric fields exist parallel to the geomagnetic field lines. Such electric fields would play a basic role in coupling the magnetosphere to the ionosphere and in the determination of the character of precipitated particles. Particle beams of appropriate charge sign will be projected upward or downward from Shuttle. The energies which are reflected from, as opposed to transmitted through, the regions of $E_{||}$ will determine the total potential drop. Time of flight will depend on the spatial extent and location of $E_{||}$. Particles may be detected either indirectly by observing the artificial aurora produced in the E region or directly by detectors on a suitably positioned subsatellite.

Since the procedures are very similar to those used for II' Electron Echo Experiment we include the indirect method here and the direct under II'.

B. Data and Its Collection

1. The quantities to be measured are:

- The parameters describing the injected beam such as particle type, energy, current, and injected pitch angle.
- The properties of the detected spot including its position, intensity, dimensions, and the phase delay between the injection of the particles and the detection of the spot.

These measurements require a particle accelerator to inject a beam of electrons or ions with keV energies and currents of $\sim$ .1 1. amp. The AMPS particle accelerator system described by IFRDSI-9 and I-11 easily meets these criteria.

The optical band imager and photometer system (OBIPS) described in IFRD III-3 is suitable for measuring the properties of the artificial spot.

a) Dynamic Range and Precision

The imager and photometer system should have a dynamic range of 10^5 and be capable of resolving a spot which covers $\sim$ .06° of arc as seen from the orbiter.

b) Acceptable Background Levels

Since the artificial spot will be relatively small and of fairly low intensity, the experiment should take place in the absence of any bright discrete aurora and during the dark of the moon. Night

airglow, starlight, and weak diffuse aurora are acceptable. The imager and photometer systems should have an instrumental background well below the natural one.

2. Location

The experiment should take place equatorward of the discrete aurora, possibly in the region of the diffuse aurora. The orbiter must be in the night time hemisphere.

a) This will severely limit tbe duration of each run because of the small amount of time spent near the auroral zone for orbital inclinations of 60° or less. Ten minutes per orbit seems reasonable.

b) Because of the importance of this experiment, the more runs made, the better. A reasonable program may consist of 6 to 8 runs per day.

c) Data Rates

Particle Accelerator - 160 bps

Imager = 4 MHz video

Photometer - 16 kbps each (OBIPS writeup)

Housekeeping - .1 kbps

Orbiter position and time housekeeping - 11.4 kbps

Total rate 4 MHz video — 27.6 kbps

For a seven day mission, a reasonable program may encompass 8 orbits/day with a run time of $\sim$ 10 min/orbit. This would result in a total of 9.3×10^5 kbits plus the video.

3. Conducting Runs

a) Parameters to be varied

particle accelerator	-	type of particle accelerating voltage current injection pitch angle beam pulse program
imager	-	focal length and field of view f-stop gain and contrast integration time pointing direction filter - wavelength
photometer	-	focal length and field of view gain filter - wavelength pointing direction

b) Preprogramming

Pre-calculate range of orbit for which geometry is favorable. Orient, stabilize spacecraft using a model of the earth's field. Determine approximate aiming direction of injector and imagers, also using a model magnetic field. (Data from the DC electric field meter (IFRD III-21) and the ion drift detector (IFRD III-1), if available, could be used as additional information to help predict beam impact location.) Selectable pulse programs for the accelerator must be available as well as a cross correlation program with variable lag between the beam pulsing and the imager/photometer output. Initial beam and imager properties must also be planned.

c) A typical run could be conducted as follows:

Complete preprogramming prior to entering darkness. Align imager and photometer system so that it views the foot of the magnetic field line passing through the orbiter. When the background conditions are tolerable, start with low beam current and energy. If the spot is detected, align imagers on the spot. Display offsets from predicted location and the delay time between injector pulse and spot detection. Measure the intensity and dimensions of the spot. Decrease particle energy until spot disappears. Sweep through injector pitch angle.

If the spot is not detected, increase current and energy until it becomes so. If no spot is seen at maximum beam power, scan imager about predicted location to see if the deflection is larger than anticipated. Computer should use correlation program to tag picture region which correlates.

This procedure should be carried out for both electrons and ions with injection occuring both up and down the magnetic field lines.

4. <u>Real Time Display</u>

a) Alphanumeric display of both beam and imager properties as well as orbiter position and status.

b) Monitor showing scene viewed by the imager, including marks showing the predicted and actual coordinates of the artificial spot.

c) Alphanumeric display of spot properties such as luminosity, dimensions, and phase delay between injection and detection.

Comments:

1. Due to the high shuttle velocity, particles which are returned to shuttle altitudes after mirroring (or after being returned by $E_{||}$ above shuttle) will be located behind the orbiter so that particle detectors onboard will have no chance to see them. Detectors on-board a maneuverable subsatellite would detect a lower particle flux than will the observation of artificial aurora, but it will be very difficult to position the subsatellite in the return beam.

2. Ground observations of the artificial aurora would be highly desirable but would also be extremely difficult to correlate with a shuttle pass because (a) it would severely limit the times when the experiment could take place and (b) viewing conditions over the ground observatory must be favorable.

3. Many orbiter passes will be required since one needs to fire both up and down the field lines with both types of particles and the time period of the experiment per pass is small.

II'. Electron Echo Experiment

A. Purpose

The objective of this type of experiment is to improve our knowledge of the topology of the earth's magnetic field and its dependence upon geophysical activity. The basic idea is to inject a beam of electrons with known current and energy and then detect them after they mirror and/or backscatter. Such an experiment should enhance our understanding of atmospheric backscatter, magnetic conjugacy, and the perturbations to charged particles moving in the magnetosphere caused by ∇B drift, curvature drift and convective electric field drift.

B. Data and Its Collection

1. The quantities to be measured are:

- The parameters describing the injected beam such as particle type, energy, current and injected pitch angle.
- The backscattered and/or mirrored return particle flux.

The first measurement requires a particle accelerator to inject a beam of electrons with tens of keV energies and currents of $\sim$ 1 ampere. The AMPS particle accelerator system described by IFRD I-9 is suitable.

An array of particle detectors is required to measure the reflected electron flux. These must be located on a subsatellite because of the perturbing effects of Shuttle and the fact that the beam will drift and the orbiter will move with respect to the predicted location of the return echo. Accurate knowledge of its position and the capability to change orbit are required.

a) Dynamic range and precision

The particle detector system should have a range of 10^5 with $\sim$ 3% precision. Subsatellite position should be known to 100m, orientation to within 1°.

b) Background

Natural background particle fluxes outside of the aurora are acceptable.

2. Location

The experiment should first be performed on "closed" field lines at low L shell values where the geomagnetic field is well known and perturbing electric and magnetic fields are a minimum.

The experiment should later be attempted at auroral latitudes.

a) The duration of each run will be determined primarily by how quickly (if at all) the reflected flux is detected by the subsatellite. Twenty minutes per orbit may be a reasonable time period to sweep through the appropriate injector/detector programs while looking for a signal from the returning flux.

b) The time required to position the subsatellite will be the major constraint on the number of runs made during a seven day mission. This time could vary a great deal, depending on how much of an orbit change is required. Two or three runs per day would seem reasonable.

c) Data Rates

Particle accelerator - 160 bps

Orbiter position time and housekeeping - 1.4 kbps

Particle detectors on subsatellite -

medium energy electrons	IFRD III-8	32 kbps
medium energy ions	IFRD III-15	25.6 kbps

Housekeeping, including attitude - 6.6 kbps

For three runs per day at 20 minutes per run, the total bit rate per mission would be ∿ 3.9×10^6 kbits from the subsatellite and 0.69×10^6 bits from the orbiter.

3. Conducting Runs

a) Parameters to be varied

accelerator — accelerating voltage
current
injection pitch angle
beam pulse program

particle detectors — adjust position of subsatellite

Program energy stepping and data accumulation times.

b) Preprogramming

Using a model of the earth's field, precalculate altitude, injection pitch angle, L-shell, energy of particles, mirror point, location of return echo, and expected time delay between particle injection and detection of echo (Data from the DC electric field meter (IFRD III-21) and the ion drift detector (IFRD III-1), if available, could be used as additional information to help predict the location of the return echo.)

c) A typical run could be conducted as follows: Align injector to the pre-calculated pitch angle which has been chosen to

give an optimum return after the particles mirror. Position subsatellite at the predicted location of the return echo. Initiate pulse program. Display flux seen by the particle detectors, look for enhanced spectrum at the proper delay time. If no reflected flux is seen, increase the current. Cross-correlate the particle detectors and beam pulses with variable lag. Vary the beam pulse program.

If no particle identification is made, change the separation of orbiter and subsatellite and try again when ready.

This program can be conducted for particles fired down the field lines into the atmosphere below Shuttle, or for particles fired up the field lines to be reflected in the other hemisphere.

4. Real Time Display

a) Alphanumeric display of beam properties as well as orbiter position and status.

b) Alphanumeric display of orbiter-subsatellite geometry (or CRT display), predicted mirror altitude, predicted location and time delay for return echo.

c) CRT display of flux, energy and pitch angle spectra of particles detected by the subsatellite.

Comments:

1. Both experiments I and II can be best performed by a scientist interacting in real time and in near real time (changing parameters from one orbit to the next). Both of the experiments are important but difficult.

2. The successful use of particle beams in these and other experiments requires that the interaction of the accelerator and beam with the near environment (a few kilometers) under various circumstances be well understood. Thus the various beam-plasma experiments should be done first using the beam diagnostics: IFRD III-3,4,5

III. Flow Dynamics Around a Controllable Test Body

The committee judged that these measurements could not be successfully done because the scale length of the various regimes of flow (essentially the Debye length of a few centimeters) is too small to map.

IV. Acoustic-Gravity Wave Generation

A. Purpose

To generate acoustic-gravity waves in the upper atmopsheres by chemical release and to observe the evolution of the disturbance produced.

The release of ∿ 1000 kg of chemical over or near an existing ground-based ionospheric radar facility such as Arecibo will allow study of the 3-dimensional wave and comparison of its growth and propagation with theoretical models.

B. Equipment on Shuttle

Gas release module:

controls: Command and time release of gas in quantities (rates) of up to 100 kg/5 sec. Command and timed release of small (∿ 1 kg) gas quantities as diagnostics.

output: Verification of release.

C. Procedure

a) Predetermine orbital time for ground observations and/or correct solar angle for optical tracking of gas (20 min ± 2.5 min before ground sunrise, 20 min ± 2.5 min after ground sunset). Altitude required 150-300 km.

b) Determine by ground communications whether seeing condition, instrumentation, and ionospheric conditions are suitable.

c) Preset release timing sequence for main release.

d) Deploy additional small quantities of gas for determination of ambient conditions.

D. Displays

a) CRT display of relative position of shuttle, release point, ground observations, and correct sun angles.

b) CRT or ALPHAMERIC display of time to release, status of release device, etc.

Comments:

1. This experiment uses Shuttle to carry the 1000 kg of material to be released, and makes minimal use of AMPS to observe the results. Observations are to be made from the ground. Since the orbit and release time will be calculated before flight, the only real time

information needed onboard is time and G & N.

2. Interesting experiment using Shuttle.

3. Makes few demands on AMPS system.

V. Scientist/AMPS Interface Study—Plasma Seeding Experiment

A. Purpose

The objective of this type of experiment is to stimulate an instability in ion-cyclotron or electron-whistler electromagnetic waves by artificially increasing the local plasma density. The experiment would test the rather well developed theory of these instabilities, particularly with regard to growth rates, scale lengths and the effects of boundary conditions on initiation of the instability. The Shuttle would be used to transport the gas module and its rocket to a few hundred kilometers altitude. AMPS Laboratory scientific instruments would provide very helpful but nonessential data for the experiment. Primary data would come from a satellite that would pass through (or very close) to the ion cloud.

A series of these experiments should be performed with the Shuttle over a long period of time—the later experiments being more elaborate and involving several gas releases in quick succession. We discuss here only an early experiment with a single gas release. The EOR also gives a binary choice for the location of the experiment command station on Shuttle or on the ground. The latter seems to us the more sensible location and we will not discuss here telemetry and other problems associated with having the command station on Shuttle.

B. Data Collection

1. Quantities to be Measured from Subsatellite

IFRD	Quantity	Dynamic Range	Precision	Background Noise Allowed
III-2	Dc electric field	0-1 V/m	10 mV/m	$\sim$ 10 mV/m
III-21	Dc magnetic field	3-6 gauss	10 γ	$\sim$ 10 γ
III-24	Ion masses/spectrum 1 KeV-500 KeV (for protons)	$\sim 10^5$ to $10^8 cm^{-2} sec^{-1} st^{-1} keV^{-1}$	30%	$\sim 10^5 cm^{-2} sec^{-1} st^{-1} KeV^{-1}$
III-16	(heavy ions)	0 to $10^5 cm^{-2} sec^{-1} st^{-1} keV^{-1}$	Factor of 2	as low as possible
	(object is to detect a small but unpredictable flux of Ba^+)			
	Electron spectrum			
III-8	1 - 30 keV	$\sim 10^{7.5}$-$10^{10} cm^{-2} sec^{-1} st^{-1} keV^{-1}$	$\sim$20%	$\sim 10^{7.5} cm^{-2} sec^{-1} st^{-1} keV^{-1}$
III-14	30 - 500 keV	$\sim 10^5$-$10^{7.5} cm^{-2} sec^{-1} st^{-1} keV^{-1}$	$\sim$20%	$\sim 10^5 cm^{-2} sec^{-1} st^{-1} keV^{-1}$
I-16	ELF-VLF Spectrum			

2. Region of Space:

at least 400 km, to get useful pitch-angle measurements for ~30 keV protons; altitude doesn't matter much when it is electron waves that are to be driven unstable.

Duration of Run: time from launch to release ~2 hr. (adjustable)
time through a 2° band of latitude ~40 sec.

Number of runs on 7-day mission: probably one, at least on early missions.

Data Rate: 39.2 kbps from subsatellite during passes through the L-shell of interest plus 40 KHz analog.

Total bits in mission, data collection: 3 min x 40 kbps = 7200 kbits. Data rate and "total bits" could be reduced by making more sparing use of the particle detectors. For example, one might use only ion detectors in an experiment aimed at stimulating instability in ion waves.

3. Narrative of Hypothetical Run

The time at which the gas-release module is launched into its prescribed orbit (~ 6 R_E equatorial apogee, few hundred-km perigee, low-degree inclination) is determined by orbital constraints, particularly the primary requirement that the module's orbit nearly intersects the orbit of the satellite that will be the primary data source, and the secondary requirement that the Shuttle orbit come close to the flux tube onto which the gas is released. The likelihood of favorable magnetospheric conditions two hours hence would be the other crucial factor in deciding the time of launch.

During a precalculated time interval, when the gas-release module is near apogee, the observing satellite and the module are satisfactorily located relative to each other so that the satellite will enter the ion cloud soon after its formation. This time period id calculated from the orbits involved, the nature of the gas release, and the electric fields measured by the primary-data satellite (ideally) or (less ideally) from Shuttle or a ground-based radar. Within this period, the release time must be chosen to correspond to conditions of low total plasma density but sufficiently high density of kilovolt electrons (protons), with sufficiently anisotropic pitch angle distributions. The crucial measurements of these particle parameters must come form the primary-data satellite, although particle measurements made from the Space Shuttle might provide helpful supplementary information about particles with very small equatorial pitch angles.

After release, the AMPS Charged Particle Detector System should be turned on for every pass through the auroral zone, at local times near that of the flux tube where the gas was released. The objectives would be to look for enhanced precipitation of electrons (protons) and for a trace of barium.

After the release, the primary-data satellite should detect greatly enhanced noise in the electron whistler (ion cyclotron) region and should also observe a smoothing of the relevant pitch-angle distribution.

The important variable parameters are the launch time and orbit parameters for the rocket carrying the gas module and the gas release time. The choice of launch time and orbit parameters will probably have to be precalculated for each of several Shuttle orbits, with a go-nogo decision made as to launch at each of these possible orbits; this decision would presumably be from the ground, and would be based primarily on data from ground magnetometers and from a spacecraft out in the solar wind.

<u>Gratuitous Comments on the Proposed Experiment</u>:

1. Very good and worthwhile experiment—a fine example of the use of the magnetosphere as a plasma physics laboratory.

2. The Space Shuttle greatly eases the problem of transporting the heavy gas module far out into the magnetosphere.

3. The AMPS instruments play a nonessential role.

a) It is difficult to determine $\underset{\sim}{E}$ in the magnetospheric equatorial plane from $\underset{\sim}{E}$ measured in the ionosphere, so we are doubtful about the usefulness of the Shuttle electric field measurements in this experiment.

b) Shuttle measurements probably won't add greatly to the information on pitch-angle distributions obtained from the primary-data satellite, if its particle detectors have good coverage of the small-pitch-angle region.

c) The search for barium traces in the ionosphere could be interesting, but not essential to the main goal of the experiment.

d) A rider on Shuttle in a near-polar orbit would have a fine view of auroral-zone activity, approximately twice every orbit period; this might help provide input to the decision on when to release the gas;

on the other hand, pictures from Electrodynamic Explorer would very likely be able to provide ground personnel with as good a view.

4. Consequently, we don't feel that this experiment, though good and important, should play a major role in determining the nature of the instrumentation and data-handling equipment in the AMPS Laboratory.

VI. and VII. Scientist/AMPS Equipment Interface Study Experiments: "Metallic Chemistry" and "Trace Species 15 - 120 km"

A. Purpose

Metallic Chemistry

The objective is to determine the chemistry of metals, originating from meteor input, interacting with the neutral atmosphere in the 85 to 150 km region. The magnitude of the interaction is larger under conditions of a meteoric shower. Such conditions aid but are not necessary to perform the experiment.

Trace Species

The objective is to determine the interrelationship of the minor neutral species that populate the 15 to 120 km altitude region. The interrelationships will involve the behavior of a group of constituents in a defined altitude region, below 50 km for example, as well as the interrelationship of constituents over the entire 15 to 120 km altitude regime. At some point in the AMPS program time variations and response of groups of constituents to a specific event — say a stratospheric warming — will become important experiment objectives.

Instrumentation

A wide variety of elements and compounds come under the general objectives of these experiments, and the possible spectral techniques are diverse. The requirements for laser sounding (LIDAR: IFRD I-1) are sensitive to the particular emission being observed. Infrared emissions as a function of height can be derived from an IR Limb Scanner (IFRD II-7), and UV absorption by terrestrial constituents, when the sun is occulted by the limb of the earth, can give abundances versus height in some cases (IFRD II-1).

The instrument selected for analysis here is a spectrophotometer (IFRD II-4) that operates in either a scanning mode or multiple-channel fixed wavelengths.

This instrument is probably better suited for investigation above 50 km than below, although the O_3 profile should be obtainable to 25 km. There are other techniques for the measurement of O_3 so that this instrument may not be required except for information above 50 km.

B. Data and Their Collection

1) The quantities to be measured are the natural and induced atmospheric emissions from 300 to 10,000 Å. This is accomplished with an array of (∿ 8) miniature monochromators.

Two basic modes of operation are envisaged:

a) spectral scanning at about 10 Å resolution;

b) high sensitivity and photometric accuracy monitoring at fixed wavelengths to be selected prior to or during the mission. The minimum sensitivity required is 1 count/sec/Rayleigh.

For the high sensitivity, fixed mode, the principal information desired is the variation in intensity from nadir to limb in the daylight. Background noise will consist of the Rayleigh scattered sunlight. In the visual and near IR the detectability of resonance scattering is then set by the reflected solar intensity by clouds over the Doppler width. This may be estimated for any particular wavelength chosen. Knowing the f-value of the atomic transition to be observed makes it possible to calculate the resonant scattering "g factor" for daytime airglow.

In the near UV ozone absorption greatly reduces the backscattered Rayleigh light. A wide variety of species can thus be examined, including metallic ions such as Mg^+.

A reasonable precision requirement would be 1° relative accuracy.

2) Measurements will be made on the dayside for abundance and height determinations. Even weak emissions of a few Rayleighs can be accurately measured in a few seconds of counting time in the UV where scattered light is not the limiting factor.

The observer can therefore obtain nadir-limb scans by pointing the instrument at the same geographic point and using the motion of the satellite to conduct the scan.

Data rates and total accumulated data will depend on the number and brightness of lines to be measured and the number of changes of spectral settings. Redundancy of measurements is important to establish geographical (e.g., latitudinal and local time) differences. Figuring 10 per cent usage of the instrument at an average data rate of 10 kbps, a 7-day mission would yield only 6×10^8 bits of read-out data, although the raw data rate is much

higher than the read-out rate. Raw data would be accumulated and processed prior to readout in a microprocesser run, for example, in a multichannel analyzer mode. Wavelength data and signal data would be read out 10 times per second with 8 bit and 16 bit accuracy respectively.

In fact a number of instruments will be used simultaneously. Some required instruments are listed in Attachment I which is a summary from the Martin Marietta presentation to the AMPS Science Working Group, Jan. 22, 1976. The limb scanners and other spectrometers each measure several constituents. (A breakdown can be found in the EOR.) The lidar will be used initially for only one constituents which can be covered and the amount of time required to shift from one species to another is unknown at this time. It is probably safe to assume that the solar satellite will have a data handling system independent of the shuttle.

The amount of data required will be at least 15 orbits per 7-day mission. Both daytime and night data will be required. Since many of the constituents to be measured exhibit diurnal variations, it will be necessary to measure continuously on consecutive orbits. Several of the instruments, e.g., cryo-limb scanner, are useful at all times of day. Others such as the near IR spectrometer and the lidar need to be used only during specified time periods. (See Attachment I for a time line breakdown.) Crew time is optimized if those instruments designed to take continuous data are allowed to do so. Several of the instruments do measure common constituents in a given altitude range. The degree of overlap has not been assessed in detail. The committee felt that all instruments were necessary at all times. This view may be modified as the capabilities of instruments such as the microwave limb scanner are assessed in more detail.

3) The rate of scan to observe a fixed location depends only on satellite altitude and it should be automated. Observations must be done in channel pairs, to provide background corrections of Rayleigh scattered light. The slit width should be adjustable by the operator when ground analysis ascertains how sensitive the center-limb variability is for providing reliable heights. For heavier atoms the thermal broadening at, say, low mesopause temperatures

is much less than the spacecraft velocity ($\sim$ 7 km/sec) and for weak emissions, where the slit width must be narrowed to obtain acceptable signal/noise ratios, the instrument should be self-correctable, with the wavelenght shift depending on altitude (i.e., velocity of the spacecraft) and viewing angle. Display may be conveniently provided by CRT's under microprocessor program control.

4) Comments

Although these are highly sophisticated measurements, little interaction is needed in real time between an operator and the equipment. The slits of the spectrophotometer are to be adjusted based on analysis made on the ground. Thus it appears that no elaborate real time display is needed on board. Sufficient house-keeping data must be displayed to determine that instruments are functioning.

VIII. Scientist/AMPS Equipment Interface Study Chemical and Dynamic Studies Using Gas Releases

A. Purpose

1. The objective of this class of experiments is to study the question of particle access to the magnetosphere and the transport and energization processes that are dominant inside the magnetosphere. (See Report of the Plasma Interactions and Flows Section of the AMPS working group, NOAA Techn. Memorandum ERL SEL-43., January 1976.)

2. The particular experiment we have selected for analysis is Tracer Element Injection in the Magnetotail (see EOR by R. W. McIntire, 11/6/75).

B. Data and Its Collection

1. The quantities to be measured are:

a) the flux and energy of medium and energetic tracer ions

b) the flux and energy of naturally occurring ions and electrons

c) the flux of thermal tracer ions (if any)

d) the optical emission of the neutral gas cloud

The dynamic range, precision, and acceptable background level for each of these quantities is not available.

2. The measurements for items a through c above are to be made at the shuttle and from a subsatellite in an equatorial orbit with apogee at 8-10 R_e in the magnetotail. Item d is to be monitored from the shuttle and from ground stations.

a. Items a through c above should be measured throughout the entire 7-day mission and longer if possible in the case of the subsatellite measurements. Item d should be measured during the entire shuttle pass during which the release occurs. A quick scan should also be conducted on the subsequent pass to verify that the gas fully ionized and/or the cloud dissipated below visibility.

b. One major release should be planned for each 7-day emission. More releases could be planned; however, the dissipation or transport time of the ions throughout the magnetosphere could be as long as several days. Also the coordination of the satellite carrying the release canister and the subsatellite (both required to be near apogee at release) could be a problem.

c. The total data rates are as follows:

		Shuttle	Subsatellite
Particle Detectors	Digital	97.3 KPBS	49.8 KBPS
	Analog	1-10 MHz	
		10-5 MHz	
Optical Band		4 MHz analog	
Imager & Photometer (possible 2 such channels)			
System (OBIPS)		16.048 KBPS	

The total mission bits for the particles experiments will be approximately 6×10^{10} bits for shuttle and about 3×10^{10} bits for the subsatellite. This may all be recorded on the ground. In addition the OBIPS will require about 3 hours of continuous recording of 2 channels of 4 MHz video analog output.

d. The onboard (shuttle) data display requirements include the OBIPS video output and digital output of the OBIPS photometer (16 KBPS) and shuttle medium energy Ion Mass Analyzer (23 KBPS). It may also be desirable to telemeter to the shuttle for display the substatellite medium energy tracer ion analyzer (25.6 KBPS). The shuttle will also require mode status readout of the 5 particle experiments on both shuttle and the subsatellite (this assumes the subsatellite modes are commandable from shuttle).

3. Typical Run Scenario

a. Predetonation activities (shuttle): (order not critical)

1. command on and select operating mode for the Energetic Ion Mass Analyzer (IFRD III-20)
2. command on and select mode for the Energetic Ion Detector (IFRD III-6)
3. command on, select mode and angle scan for Medium Energy Ion Detector (IFRD III-9)
4. command on, select mode, angle scan and PHA center point for Energetic Electron Detector (IFRD III-11)
5. command on, select mode and set angle control for the Medium Energy Ion Mass Analzyer (IFRD III-12) confirm digital data display functional for this detector
6. activate and check out OBIPS video and photometer system. Preset printing conditions to detonation point and confirm digital and video display functional (IFRD II-3).

b. Predetonation activities (subsatellite):

1. command on and select mode for Energetic Ion Mass Analyzer (IFRD III-24)
2. command on and select mode for medium Energy Ion Analyzer (IFRD III-15), verify display
3. command on and select mode for Energetic Ion Detector (IFRD III-13)
4. command on and select mode, angular scan and PHA center energy for the Energetic Electron Detector (IFRD III-14)
5. command on and select mode and bias for Subsatellite Ion Mass and Distribution Analyzer (IFRD III-16)
6. confirm orbital position of subsatellite. Must be approaching apogee near midnight as gas release satellite approaches apogee in the tail near the equator but in sunlight. Shuttle must be crossing the terminator toward the nightside of the earth. <u>This is the required satellite configuration at detonation</u>.

c. Post-Detonation activities; 1st and 2nd nightside shuttle passes:

1. aim OBIPS at detonation point and look for an indication of the gas cloud on the video and photometer outputs. Keep OBIPS aimed at the cloud
2. if cloud not visible switch to long integration time modes until the cloud is detected
3. if cloud still not detectable begin preprogrammed angular scan of OBIPS to confirm proper pointing direction
4. monitor subsatellite and Shuttle Tracer ion experiment digital outputs (IFRDs III-12,15). Ions in the mass range of the Tracer gas may be indicated as soon as a minute after detonation however their arrival time will depend on solar wind conditions
5. monitoring of the OBIPS should continue until the gas cloud dissipates below visibility

6. monitoring of the ion tracer experiment output should continue throughout the duration of the mission

d. Post-Run activities:

1. deactivate all shuttle particle experiments and the OBIPS

4. Data Format and Display

a. The OBIPS should be a standard video display with raster marks indicating coordinates.

b. The digital data, photometer and tracer ion detectors can be TV displays and/or line printer output vs. time and other relevant parameters such as mass, energy, or wavelengths.

IX, X, & XI. Experiments

The descriptions of experiments IX, X, & XI are taken verbatim from Aerospace Report #ATR-76(7520)-3 prepared by H. C. Koons for Rice University.

IX. ELF/VLF Antenna Development

A. Purpose

The goal of the ELF/VLF antenna development effort is to provide a source of electromagnetic waves in the frequency range from 1 kHz to 40 kHz for the AMPS facility. This source will be used for magnetospheric, communications and plasma physics research. Several candidate antennas are available. They include a long electric-dipole antenna, a magnetic loop antenna, and various configurations of charged particle beam antennas.

The particular experiment we have selected for analysis is the development of an electric dipole antenna source. Initial experiments are required to validate existing theories for antenna impedance, radiation resistance, radiation patterns, and plasma sheath properties. This will be accomplished by measuring the impedances, near fields, and far fields under various plasma conditions.

B. Data and Its Collection

1. Quantities to be measured.

(1) Parameter: Antenna Impedance
Dynamic Range: 1Ω to $10^6\Omega$
Precision: 5%
Noise Level: $< 1\Omega$
Data Rate: 80 bps

(2) Parameter: Electric Field Intensity
Dynamic Range: 90 dB
Precision: 5%
Noise Level: -40 $\mathrm{dB\mu V/m\text{-}Hz^{1/2}}$
Data Rate: 125 bps, 600 Hz analog, 30 kHz analog

(3) Parameter: Magnetic Field Intensity
Dynamic Range: 90 dB
Precision: 5%
Noise Level: -60 $\mathrm{dBpT/Hz^{1/2}}$
Data Rate: 125 bps, 600 Hz analog, 30 kHz analog

(4) Parameter: Driving Frequency
Dynamic Range: 100 Hz to 100 kHz
Precision: 1 Hz
Noise Level: N/A
Data Rate: 18 bps

(5) Parameter: Driving Voltage
Dynamic Range: 10 mV to 100 kV
Precision: 5%
Noise Level: < 10 mV
Data Rate: 192 bps and 20 kHz analog

(6) Parameter: Ion Mass and Distribution
Dynamic Range: 10^2 to 10^7 cm^{-3}
Precision: 5% for three dominant species
Noise Level: < 10^2 cm^{-3}
Data Rate: 2430 bps

(7) Parameter: Ion Temperature
Dynamic Range: 300°K to 3000°K
Precision: 5%
Noise Level: N/A
Data Rate: Included under No. 6

(8) Parameter: Electron Density
Dynamic Range: 10^2 to 10^7 cm^{-3}
Precision: 5%
Noise Level: <10^2 cm^{-3}
Data Rate: 20 kbps

(9) Parameter: Geomagnetic Field
Dynamic Range: 0.01 to 1 G
Precision: 1%
Noise Level: 10^{-4} G
Data Rate: 192 bps

(10) Parameter: Electron Temperature
Dynamic Range: 300°K to 10,000°K
Precision: 5%
Noise: N/A
Data Rate: Included under No. 8

(11) Parameter: Angle between antenna axis and geomagnetic field

Dynamic Range: $\pm$ 180°

Precision: 1°

Noise: N/A

Data Rate: Derived

(12) Parameter: Range to Subsatellite

Dynamic Range: 10 m to 1000 km

Precision: 1% or 5 km whichever is smaller

Noise: N/A

Data Rate: Derived

(13) Parameter: Location of Shuttle and of Subsatellite

Dynamic Range: $10\text{-}10^{4}$ m

Precision: 1% of range or 5 km box whichever is smaller

Noise: N/A

Data Rate: Derived

(14) Parameter: Electric and Magnetic Field Spectra

Dynamic Range: 100 kHz, 90 dB

Precision: 5%

Noise: See No. 2 and No. 3

Data Rate: Derived

(15) Parameter: Supply Current

Dynamic Range: 10^{-8} A to 100 A

Precision: 5%

Noise Level: $< 10^{-8}$ A

Data Rate: 192 bps and 20 kHz analog

(16) Parameter: Box Temperatures

Dynamic Range: -20°C to + 100°C

Precision: 2°C

Noise Level: N/A

D-ta Rate: 32 bps

(17) Parameter: Housekeeping and Status

Dynamic Range: 0-5 V

Precision: 1%

Noise Level: 40 mV

Data Rate: 240 bps

(18) Parameter: Boom Length

Dynamic Range: 0-300 m

Precision: 1%

Noise Level: N/A

Data Rate: 32 bps

2. The measurements are to be made in all accessible regions of space during the development phase of the program. Operation in a dominantly 0^+ and a dominantly H^+ plasma is desired in order to validate existing theories.

a) The duration of each run should be one orbit.

b) Two orbits per day on a 7-day mission are desired. The range of parameters is so large that it is unlikely that either redundancy or statistical improvement would result from this duty cycle. The development phase will be iterative with controllable parameters varied based on experience gained during earlier orbits.

c) The total bit rate excluding the 20 kbps required for a Langmuir probe is 3658 bps or 2.2×10^5 bits-per-minute or 2×10^7 bits-per-orbit plus 100 kHz analog. For two orbits a day for a seven-day mission, the total bit requirement is 275 megabits.

3. At least one orbit will be required to deploy the electric dipole antenna. An intermediate length such as 50-m tip-to-tip would be chosen for the initial tests. Based upon real-time sensor data, a frequency between the lower-hybrid resonance frequency and the electron gyrofrequency would be selected and a low voltage (10 to 100 mV) would be applied to the antenna. The impedance of the antenna would be measured to verify that the circuits are functioning properly. The frequency would then be swept and the impedance measured and displayed on an oscilloscope. The driving voltage would then be step-wise increased while the impedance sweeps continue. This must be continued until the maximum drive voltage is attained or until a voltage breakdown occurs. Spectra of the voltage and current waveforms are also collected during this time. This procedure is repeated until a representative set of data is collected under the various plasma parameter sets available to the mission.

Following the successful completion of the impedance measurements, a subsatellite would be launched to measure the field patterns. The first few orbits would require station keeping to perform the measurements within 1 km of AMPS. The driving frequency would be

performed below the lower-hybrid resonance frequency, but above the ion gyrofrequency. In this frequency range the index of refraction surface is closed and radiation should reach the subsatellite irrespective of its position about the shuttle. The operator on Spacelab would tune the receivers on the subsatellite and vary the receiver gain as required. He would also select the field component(s) he wishes to spectrum analyze and display. On the basis of these data, he wwuld optimize the frequency and voltage drive.

Following successful completion of measurements below the lower-hybrid resonance, the frequency would be shifted above and resonance cone measurements would be made. This will involve frequency sweeps based on real-time data from the plasma sensors.

a) The primary parameters of interest are the electron density, ion mass distribution, geomagnetic field intensity, and the angle of the antenna axis with respect to the geomagnetic field. The parameters in the apparatus that can be varied are the driving frequency, driving voltage (or current), the antenna orientation (shuttle orientation), antenna length, and the duration of the signal.

b) No parameter variations <u>must</u> be pre-programmed. Frequency sweeps and voltage (current) steps can be pre-programmed to facilitate data collecting after the initial tests.

c) Frequency selection must be based on real time data. It will be based on the lower-hybrid resonance frequency which is a function of the electron density, the geomagnetic field strength, and the ion mass distribution.

4. Real Time Data Display

a) Alphanumeric display of the following parameters:

(1) Driving Frequency
(2) Driving Voltage
(3) Complex Antenna Impedance
(4) Antenna Length
(5) Field Amplitudes (6 functions)
(6) Ion Composition
(7) Electron Density
(8) Low Hybrid Resonance Frequency
(9) Subsatellite Range
(10) Antenna Pointing
(11) Red lines ($\leq$ 16 functions)

(12) Receiver Gains (6 functions)

(13) Receiver Frequency (6 functions)

(14) Resonance Cone Angle

b) CRT display

(1) Shuttle - Subsatellite Map

(2) Dynamic spectra of electric and magnetic field intensity

(3) Ampligram spectrum

A spectrum analyzer equivalent to the Spectral Dynamics Corp. Model SD301 D or the Sanders Model SA240 is required for the dynamic spectra and ampligram displays.

X. Beam Excitation of Plasma Waves

A. Purpose

To develop a ULF/ELF/VLF wave source which is suitable for a small satellite.

Conventional ELF/VLF antennas that have been proposed for satellite applications involve electric dipoles which are several hundred meters long or magnetic loop antennas which require many turns of a highly conducting material with dimensions of ten's of meters. Although such antennas can be used on Spacelab, they are generally not suitable for Scout or Delta-Explorer class satellite. This limits the regions which are accessible to such wave sources. In particular, it is desirable to perform experiments within the primary wave-particle interaction region at very high altitudes near the geomagnetic equator. This region is only accessible to smaller satellites.

Laboratory and rocket measurements show that a modulated ion or electron beam is a source of plasma waves. The objective of this program is to develop a controlled source of radiation.

B. Data and Its Collection

1. This experiment requires an ion accelerator (IFRD No. I-11) and/or an electron accelerator (IFRD No. I-9), ELF/VLF receivers (IFRD No. I-16), Ion Mass and distribution analyzer (IFRD No. III-10, 16), and magnetometers (IFRD No. 39), Radio Freq. Sounder Receiver (IFRD No. III-2).

The following parameters are to be measured:

(1) Parameter: Beam Voltage
Dynamic Range: 1-30 kV
Precision: 1%
Noise Level: 10 V
Data Rate: TBD

(2) Parameter: Beam Current
Dynamic Range: 0-10 A
Precision: 1 ma
Noise Level: 1 ma
Data Rate: TBD

(3) Parameter: Electric Field Intensity
Dynamic Range: 90 dB
Precision: 5%

(3) Cont'd.

Noise Level: -40 dBμV/m-Hz$^{1/2}$

Data Rate: 125 bps, 600 Hz analog, 30 kHz analog

(4) Parameter: Magnetic Field Intensity

Dynamic Range: 90 dB

Precision: 5%

Noise Level: -60 dBpT/Hz$^{1/2}$

Data Rate: 125 bps, 600 Hz analog, 30 kHz analog

(5) Parameter: Driving Frequency

Dynamic Range: 1 Hz to 100 kHz

Precision: 1 Hz

Noise Level: N/A

Data Rate: 18 bps

(6) Parameter: Ion Mass and Distribution

Dynamic Range: 10^2 to 10^7 cm^{-3}

Precision: 5% for three dominant species

Noise Level: < 10^2 cm^{-3}

Data Rate: 2430 bps

(7) Parameter: Ion Temperature

Dynamic Range: 300°K to 3000°K

Precision: 5%

Noise Level: N/A

Data Rate: Included under No. 6

(8) Parameter: Electron Density

Dynamic Range: 10^2 to 10^7 cm^{-3}

Precision: 5%

Noise Level: < 10^2 cm^{-3}

Data Rate: 20 kbps

(9) Parameter: Geomagnetic Field

Dynamic Range: 0.01 to 1 G

Precision: 1%

Noise Level: 10^{-4} G

Data Rate: 192 bps

(10) Parameter: Electron Temperature
Dynamic Range: 300°K to 10,000°K
Precision: 5%
Noise: N/A
Data Rate: Included under No. 8

(11) Parameter: Angle between antenna axis and geomagnetic field
Dynamic Range: ± 180°
Precision: 1°
Noise: N/A
Data Rate: Derived

(12) Parameter: Range to Subsatellite
Dynamic Range: 10 m to 1000 km
Precision: 1% or 5 km whichever is smaller
Noise: N/A
Data Rate: Derived

(13) Parameter: Location of Shuttle and of Subsatellite
Dynamic Range: $10-10^4$ m
Precision: 1% of range or 5 km box whichever is smaller
Noise: N/A
Data Rate: Derived

(14) Parameter: Electric and Magnetic Field Spectra
Dynamic Range: 0.1 Hz to 15 MHz, 90 dB
Precision: 5%
Noise: See No. 3 and No. 4
Data Rate: Derived

(15) Parameter: Box Temperatures
Dynamic Range: -20°C to +100°C
Precision: 2°C
Noise Level: N/A
Data Rate: 32 bps

(16) Parameter: Housekeeping and Status
Dynamic Range: 0-5V
Precision: 1%
Noise Level: 40 mV
Data Rate: 240 bps

2. The measurements are to be made in all accessible regions of space during the development phase of the program. Operation in a dominantly O^+ and a dominantly H^+ plasma is desired in order to validate existing theories.

a) The duration of each run should be one orbit.

b) Two orbits per day on a 7-day mission are desired. The range of parameters is so large that it is unlikely that either redundancy or statistical improvement would result from this duty cycle. The development phase will be iterative with controllable parameters varied based on experience gained during earlier orbits.

c) The bit rates for the beam voltage and current monitors should be comparable to the same numbers for the ELF/VLF Antenna Development experiment. The rate is 3650 bps or 275 megabits for two orbits a day during a seven-day mission.

3. The controlled beam excitation experiments would begin after the initial testing of the beam accelerators. During the initial accelerator testing the wave receivers would collect data on the natural emissions generated by the beams. The spectra would be displayed in real-time to the operator or alternately to investigators on the ground. These measurements would be used to plan the stimulation experiments.

For the controlled experiments, the operator would choose the beam configuration and modulation program.

a) The ambient parameters of interest are the electron density, the ion mass distribution, the geomagnetic field intensity, and the electron and ion temperatures. The experiment parameters that can be varied are the beam voltage and current, the ion mass in the ion beam, the beam spreading, the orientation of the beam, and the modulation program.

b) No parameter variations <u>must</u> be pre-programmed. The beam voltage, beam current, and modulation program can be pre-programmed to facilitate data collecting after the initial tests.

c) Since the response of the ionosphere to modulated beams is almost entirely unknown, optimization would be based on the display of the amplitude and spectrum of the received signals.

4. Real Time Data Display

a) Alphanumeric display of the following parameters: beam voltage, beam current, beam ion, ambient ion composition, ambient electron density, field amplitudes (6 functions), ion gyrofrequency, plasma frequency, subsatellite range, beam orientation, redlines ($\leq$ 16 functions), receiver gains, receiver frequency, resonance cone angles.

b) CRT Display

(1) Shuttle - Subsatellite map

(2) Dynamic spectra of electric and magnetic field VLF and HF intensity. 0-15 MHz in selectable frequency bands.

(3) Ampligram spectrum

VLF spectrum analyzers equivalent to the Spectral Dynamics Corp. Model SD301D or the Sanders Model SA240 are required for the dynamic spectra and ampligram displays.

MF/HF spectrum analyzers equivalent to the Hewlett Packard Model 8553 are required for the ampligrams from the radio frequency sounder. Special purpose equipment may be required to display dynamic spectra at HF.

XI. HF Wave/Particle Interaction

A. Purpose

To experimentally validate plasma theories in the areas of plasma wave dispersion, wave-particle and wave-wave interactions, plasma turbulence and plasma wave instabilities. These phenoman are of fundamental importance to laboratory, ionospheric, magnetospheric, solar, and astrophysical plasma problems. To measure antenna properties at plasma resonances. To develop plasma wave diagnostic techniques that can provide reliable measurements of electron temperature and density and magnetic field strength in the vicinity of a large spacecraft such as the Space Shuttle.

B. Data and Its Collection

1. Quantities to be measured:

(1) Parameter: Antenna Length
Dynamic Range: 0 to 100 m tip-tip
Precision: 1%
Noise Level: N/A
Data Rate: 24 bps

(2) Parameter: Transmitter Frequency
Dynamic Range: 0.1 to 20 MHz
Precision: 1 Hz
Noise Level: N/A
Data Rate: 4096 bps

(3) Parameter: Video output from receiver
Dynamic Range: TBD
Precision: TBD
Noise Level: TBD
Data Rate: Analog 30 kHz, two channels

(4) Parameter: Receiver IF
Dynamic Range: TBD
Precision: TBD
Noise Level: TBD
Data Rate: Analog 2 MHz, two channels

(5) Parameter: Receiver AGC
Dynamic Range: 90 dB
Precision: 5%
Noise Level: TBD
Data Rate: 8192 bps

(6) Parameter: Receiver frequency
Dynamic Range: 0.1 to 20 MHz
Precision: 1 Hz
Noise Level: N/A
Data Rate: 8192 bps

(7) Parameter: Angle between antenna axis and geomagnetic field direction
Dynamic Range: 0 to 180 deg.
Precision: 0.1 deg.
Noise Level:N/A
Data Rate: 80 bps

(8) Parameter: Angle between antenna axis and shuttle velocity vector
Dynamic Range: 0 to 180 deg.
Precision: 0.1 deg.
Noise Level: N/A
Data Rate: 80 bps

(9) Parameter: Antenna Potential
Dynamic Range: -100 V to +100 V
Precision: 10 mV
Noise Level: TBD
Data Rate: 80 bps

(10) Parameter: Antenna Impedance
Dynamic Range: 1 Ω to $10^6 \Omega$
Precision: 5%
Noise Level: $< 1 \Omega$
Data Rate: 80 bps

(11) Parameter: Ion Mass and Distribution
Dynamic Range: 10^2 to 10^7 cm^{-3}
Precision: 5% for three dominant species
Noise Level: $< 10^2$ cm^{-3}
Data Rate: 2430 bps

(12) Parameter: Ion Temperature
Dynamic Range: 300°K to 3000°K
Precision: 5%
Noise Level: N/A
Data Rate: Included under No. 11

(13) Parameter: Electron Density

Dynamic Range: 10^2 to 10^7 cm^{-3}

Precision: 5%

Noise Level: < 10^2 cm^{-3}

Data Rate: 20 kbps

(14) Parameter: Geomagnetic Field

Dynamic Range: 0.01 to 1 G

Precision: 1%

Noise Level: 10^{-4} G

Data Rate: 192 bps

(15) Parameter: Electron Temperature

Dynamic Range: 300°K to 10,000°K

Precision: 5%

Noise Level: N/A

Data Rate: Included under No. 13

(16) Parameter: Box Temperatures

Dynamic Range: -20°C to +100°C

Precision: 2°C

Noise Level: N/A

Data Rate: 32 bps

(17) Parameter: Housekeeping and Status

Dynamic Range: 0-5 V

Precision: 1%

Noise Level: 40 mV

Data Rate: 240 bps

2. The measurements are to made in all accessible regions of the ionosphere. Operation in a dominantly O^+ and in a dominantly H^+ plasma is desired. The following orientations for the radiating antenna are required: (1) constant in space, (2) constant with respect to the Shuttle velocity vector, (3) constant with respect to the geomagnetic field direction, and (4) rapid changes in orientation (90 deg in one minute) when the dipole is only partially extended.

a) The duration of each run should be one orbit.

b) Two orbits per day on a seven-day mission are desired. The range of parameters is so large that it is unlikely that either redundancy or statistical improvement would result form this duty cycle.

c) The total data rate excluding the 20 kbps required for

a Langmuir probe is 23718 bps or 1.8×10^9 bits for two orbits per day for a seven-day mission.

3. A major portion of an orbit will be required to deploy the transmitting and receiving antennas. An intermediate length would be chosen for the initial measurements. The first mode chosen would be a swept frequency mode where the entire frequency range is covered in as short a time as is feasible. An ionogram display would be available to the operator in the Spacelab. The various plasma resonance frequencies would be determined from the ionogram. A prearranged experiment plan including antennae and vehicle orientation, transmitter program (pulsed, swept, cw) would be followed with the operator changing parameters as required. This is a highly interactive experiment because the plasma resonance frequencies will be continuously changing and the operator must respond to optimize the scientific information gained.

a) The primary parameters of interest are the electron density, geomagnetic field intensity, and the angle of the antenna axis with respect to the geomagnetic field and satellite velocity vectors. The parameters in the apparatus that can be varied are the driving frequency, driving voltage (or current), the antenna orientation (shuttle orientation), antenna length, and the duration of the signal.

b) No parameter variations _must_ be pre-programmed. Frequency sweeps, and voltage (current) steps can be pre-programmed to facilitate data collecting.

c) Frequency selection must be based on real time data. It will be based on plasma resonance frequencies which are a function of the electron density, the geomagnetic field strength, and the antenna orientation.

4. Real Time Data Display

a) Alphanumeric display of the following parameters:

(1) Driving Frequency

(2) Driving Voltage

(3) Complex Antenna Impedance

(4) Antenna Length

(5) Ion Composition

(6) Electron Density

(7) Antenna Pointing ($\leq$ 10 functions)

(8) Redlines ($\leq$ 16 functions)

(9) Plasma Frequency

(10) Electron Gyro-Frequency

(11) Receiver Gains - (6 functions)

(12) Receiver Frequency (6 functions)

(13) Resonance Cone Angle ($\leq$ 3 functions)

b) CRT Display

(1) Ionogram Display

(2) Ampligram spectrum

(3) Amplitude vs. time display

DISCUSSION OF REQUIREMENTS

These experiments may be classified according to their data requirements into three groups. This simplifies the discussion and allows us to refer to other experiments as belonging in one of the groups.

• There is, first, a type of experiment in which little or no significant management can be exerted during a mission. Experiments IV, V, VI-VII, and VIII belong in this group either because the active portion is just a release, and/or the principal observations must be performed from the ground or a remote satellite, and/or the on-board observing instruments can have enough dynamic range that they need only be turned on and need no adjusting. For these, housekeeping status data must be available in real time; scientific data may be examined in some leisure on the ground.

When the imager is used for supporting (as opposed to essential) measurements the operator will use its monitor to adjust it for optimal resolution, definition, etc. This would be the case, for example, with V and VIII.

Observations of the plasma and energetic particle environment must be made from a remote satellite (several R_E) in order to determine whether a release is to be made in the case of experiments V and VIII. Data must be displayed in real-time somewhere. Although the display could appear on board orbiter, it appears that mission control on the ground is most logical. The release will most probably be commanded from there, not orbiter, and a team of experimenters can have access to the data.

The atmospheric composition experiments may in some cases be carried out with a lidar system, although VI and VII do not discuss this method. If the lidar is used, real-time control will be exerted on board Shuttle, and suitable displays will be needed. These will surely include, in addition to housekeeping, the display of returned intensity versus wavelength.

• A second set of experiments requires that data be evaluated within the period of an orbit so that adjustments can be made on a following orbit. Measurements requiring the use of a near subsatellite

to detect particles or radiation are in this set and include I, II, and IX (also possibly X and XI). The position of a subsatellite with respect to orbiter can be adjusted in the course of an orbit, but not instantaneously.

• The third type of measurement includes those cases where immediate adjustments should be made to apparatus, based on the data return. Devices that require this sort of attention include the particle accelerators, the imager and the ELF/VLF transmitters and receivers, as used in experiments I, II, IX, X, XI.

An important set of measurements of this latter type, which we were not asked to analyze, is the investigation of beam-plasma interactions near the orbiter. As noted after the discussion of II', these experiments should be done before or concurrently with the magnetospheric investigations such as I and II, II' that use accelerated beams as probes. The objective of the beam-plasma studies is to understand the evolution and propagation of particle beams in various plasmas from the point where they leave the accelerator until they reach a final stable state of further propagation. The background plasma parameters, electromagnetic spectrum, and the beam particle velocity distribution will be measured along the beam at increasing distance from the accelerator as the beam's injection parameters are varied (energy, current, pitch-angle) and as Shuttle encounters different environments. Detectors will be mounted first on a manipulator arm and then on a free flyer for studies out to, say, 10 km. The positions of the detector packages will be adjusted in real time in response to the detector outputs. The nearby beam will be viewed by an imager. An imager monitor and graphic displays of detected particle spectra, and rf spectra will be needed. The imager monitor should show the geomagnetic field line through the accelerator (which is the nominal beam path) and the location of the arm or sub-satellite mounted probe.

COMBINED COMPUTATION AND DISPLAY REQUIREMENTS

The real-time and near-real-time data requirements of the 10 experiments studied can be accommodated as described below and shown by Figure 1 in block diagram form. As we have discussed previously, all of this equipment could be operated at mission control on the

ground. However, we have drawn Fig. 1 as if the equipment were on board Shuttle orbiter either in the cabin or in Spacelab-AMPS. A telemetry link from subsatellite to orbiter would be used in place of hard lines in some cases.

Display devices

- Imager monitor (CRT) + hard copier
  - Image viewed by camera-direct video
  - Field line through orbiter / Look direction of photometers } computer generated
  - Time and pointing angle should be displayed in the border as alphanumeric characters.
- Graphics display (CRT) + hard copier
  - Particle energy and pitch angle spectra
  - Optical spectrometer output converted to a spectrum } digital computer
  - Location of subsatellite
  - Ampligram / Dynamic spectrum } ELF/VLF receiver and analog analyzer
  - Time and identification of the plot should be displayed in alphanumeric characters
- Alphanumeric display - (either CRT or LED, lights, etc.)
  - Instrument status and housekeeping
  - Selected data output
  - Time, position, altitude

Computation

- Video
  - Direct analog from camera to monitor
  - Integration mode available
  - Video tape storage of 20 min of data for review in flight.
- Analog
  - Convert output of receiver to ampligrams or dynamic spectra and format for display.
- Digital
  - Convert bit stream from particle and plasma diagnostic packages to spectra and format for display purposes.
  - Calculate cross correlation between selected inputs with variable delay.

Using time, position, and attitude (G & N) from Shuttle-Orbiter and a stored description of the geomagnetic field calculate

- Display of field line for monitor
- Pointing information for accelerator, imager, photometer, and spectrometer

Provide manipulator arm or subsatellite position for display on monitor

Provide data for housekeeping and status display controlled by keyboard input

Provide 100 min recording at highest bit rate

TABLE II

Experiment	Bit Rates From Experiment and Other Inputs	Computations Required	Displays	Location Pointing Subsatellite	Length of Observations
I Anderson	Subsat Particle det ~32 kb/s Attitude 6.6 Position Orbiter Video 4 mHz Phot 16 kb/s	Calculate field line for TV monitor from model field and orbiter attitude & position. Calculate phot & accelerator. Cross correlation	TV monitor Alpha-numeric display	Darkness-initially below auroral zone. Point imager along B. Accelerator at specified angle. May require subsatellite behind orbiter.	30 min/orbit 4 orbits/day
II Casserly & Wolf	Attitude 11 4	Calculate field line for TV monitor from model field and orbiter attitude & position	TV monitor Alpha-numeric display	Darkness-in auroral zone. Accelerator upward at specified pitch angle. Imager points downward along B. Subsatellite trails behind orbiter.	10 min/orbit Many orbits At high inclination 8 orbits/day
III Cloutier	N O A N A L Y S I S				
IV Cloutier	* Time		Time Display	Release over selected ground site	One shot only
V Freeman, Wolf, & Hills	Subset Particle det 39 2 Attitude 6.6 Position	Calculate energy & pitch angle & relationship of $\underline{E}$ & $\underline{B}$ from bit stream from subsatellite *	CRT display of particle pitch angle & energy spectra. CRT display of electric field vector wrt magnetic field. Time	Orbiter observes every pass through auroral zone after release Instrumental release satellite at 6 R_E. One release per mission initially	Instrumental satellite observes continuously after release AMPS observes in auroral zones after release
VI Stebbings	Orbiter 10 kb/s 6×10^8 bit total	Convert bit stream? to spectrum. *	CRT display of wavelength? spectrum. *	Daylight Nadir to limb scans. Other modes require limb pointing & scanning.	70 min/orbit At least 15 orbits/ 7 days
VII Stebbings					

Experiment	Bit Rates From Experiment and Other Inputs	Computations Required	Displays	Location Pointing Subsatellite	Length of Observations
VIII Freeman & Wolf	Subsat Particle det ∿ 49.8 kb/s Oribter Particle det 97.3 Analog 1-10 mHz 10-5 mHz Obips 4 mHz 16 kb/s *	Calculate field line for TV monitor from model field and orbiter attitude & position. Construct mass spectrum from bit stream. *	TV monitor Alpha-numeric display. CRT display of mass spectrum. *	For gas release in tail near equator. equator. Subsatellite at 8-10 R_E apogee in tail at midnight. Orbiter at terminator entering darkness.	Imager monitor for estimated 2 orbits after release. Ion mass monitor for remainder of mission.
IX Koons	Orbiter and later subsat. Langmuir probe 20 kb/s Attitude & time 11.4 Subset position Transmitter-rec 37.7 kb/s analog 100 kHz Ion Masses 2.4 subs 72 orb.	Compute orbiter - Subsatellite map and antenna pattern overlay Computations for alpha-numeric display.	Alpha-numeric display Orbiter-subsatellite map with antenna pattern overlay. CRT display of dynamic spectra and ampligram.	Measurements are desired at as great a range of locations as possible. The angle between $\vec{B}$ and antenna or electron beam axes will be allowed to vary systematically on different runs. A subsatellite is needed for IX to map antenna patterns.	Runs are 1 full orbit. 2 orbits per day for entire mission.
X Koons	Same as IX but add 3 6 kb/s information on beam.	Same as IX	Same as IX	Same as IX	
XI Koons	Same as IX plus 24 kbit	Same as IX	Same as IX	Same as IX	

*Calculation and display can be done on the ground (No real time analysis.)

TIMELINE OF ORBITAL OPERATIONS

We have assumed that each of the 10 experiments is to be carried out during 7 day mission, of which the first and last days are taken up by injection and de-orbit activities. This does not mean that they will be exhaustively executed, but measurements for each will be made during this mission. We also assume that

- The imager can be used only in darkness.
- The limb scanner can be used only in daylight.
- The orbiter cannot be manuevered to satisfy other experiments when the VLF antennas are extended.
- That input-output experiments and electron echo are most feasiable at high latitudes.
- That $E_{||}$ will most likely be detected in the auroral zone.

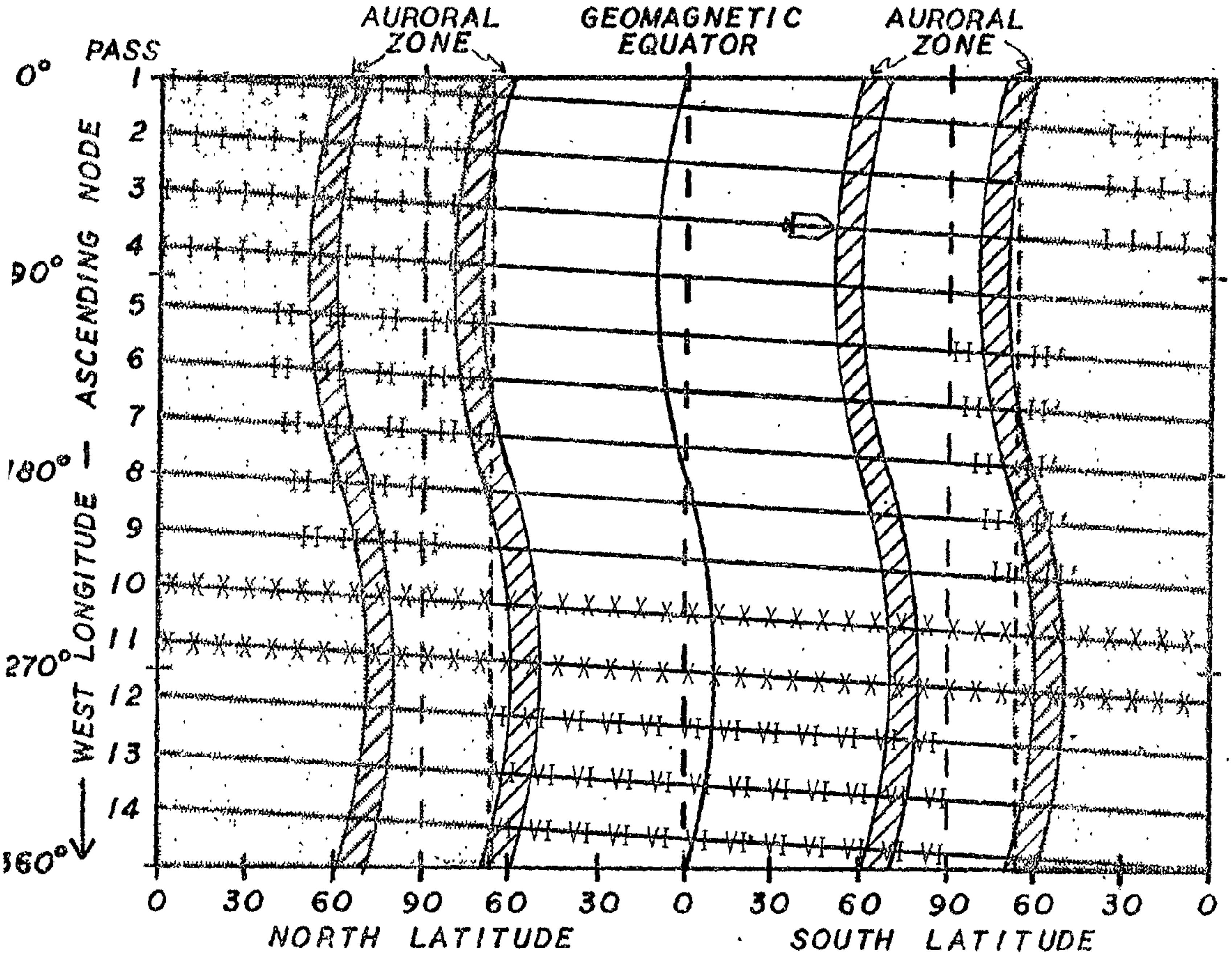
Obviously a high inclination (at least 57°) orbit is needed, and the time of launch must be chosen near one solstice putting a polar cap in shadow. The orbiter must be near the noon-midnight meridians.

We have chosen a 90° inclination orbit to simplify our mapping, and we assume an orbital period of exactly 1/14 days $\simeq$ 102 min. Fig. 2 shows successive orbits as straight lines with time having a uniform scale. There is one page for each of 5 days of operations.

For an orbit of arbitrary inclination two figures would give a clearer picture of the geometry. One would show the orbital ground track on a conventional world map, probably a Mercator projection. The other, like Fig. 2, would show successive ground tracks as straight lines, with the distorted geographic or geomagnetic grid computer plotted. For 90° inclination the two figures become one.

In Fig. 2a we show the daily schedule for days 2 and 3 of the mission. Fig. 2b shows the day, day 4, for release experiments V and VIII. On Day 5, 6 we return to the scheulde of Fig. 2a except that the ion mass spectrograph continues to operate to detect that the ion mass spectrograph continues to operate to detect Ba^+ released in VIII. These two experiments are similar but have different objectives. One instrumental satellite with 6 R_E apogee and two barium release cannisters can carry out the experiments. These should be launched from a separate Shuttle or other booster before AMPS is put into orbit. The exact timing of the releases depends

on the orbits achieved. Probably a whole day would be devoted to these release experiments.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GEOMAGNETIC EQUATOR
AURORAL ZONE
PASS
0°
90°
180°
270°
360°
ASCENDING NODE
WEST LONGITUDE
1
2
3
4
5
6
7
8
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11
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13
14
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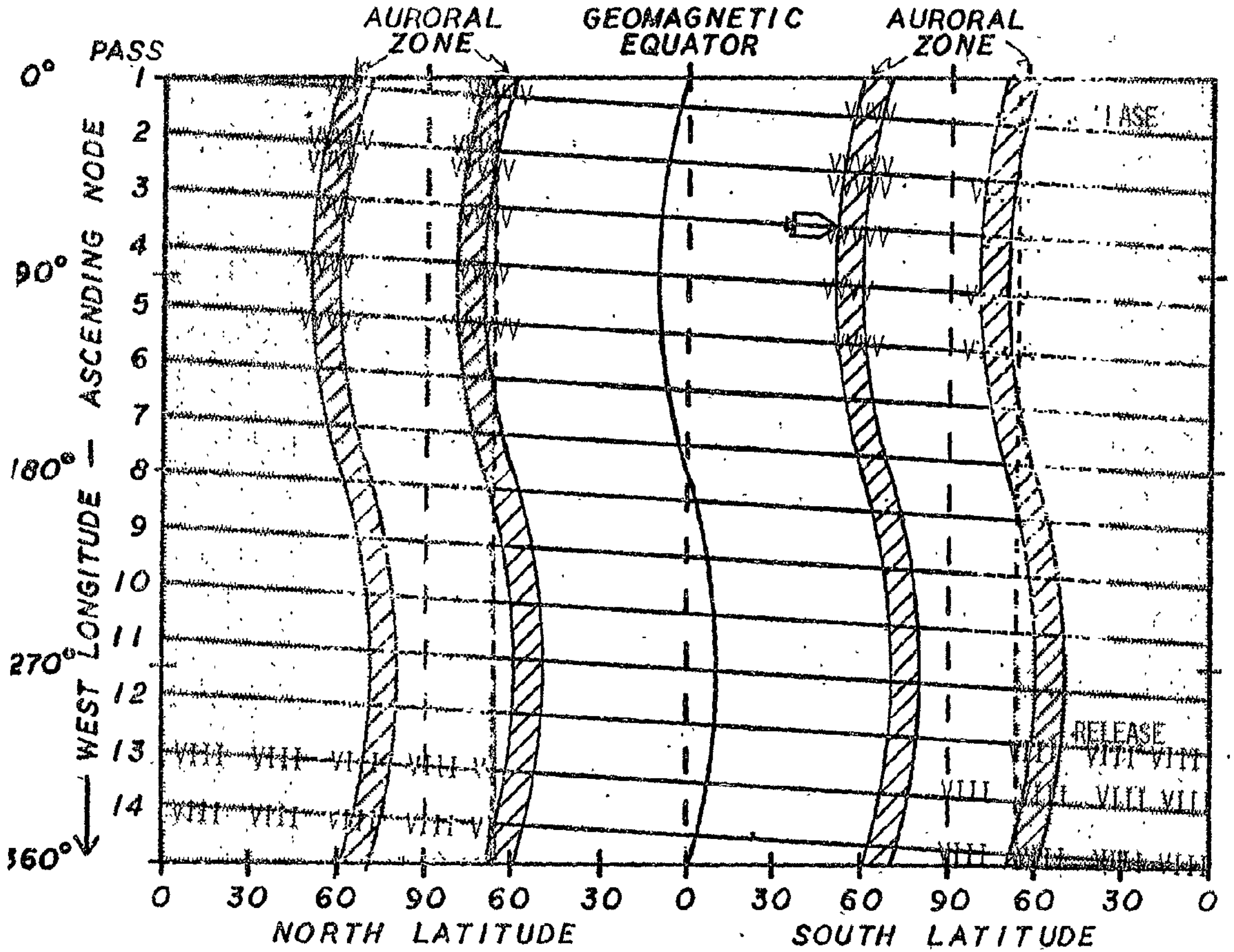
NORTH LATITUDE
SOUTH LATITUDE

2 a



2 b

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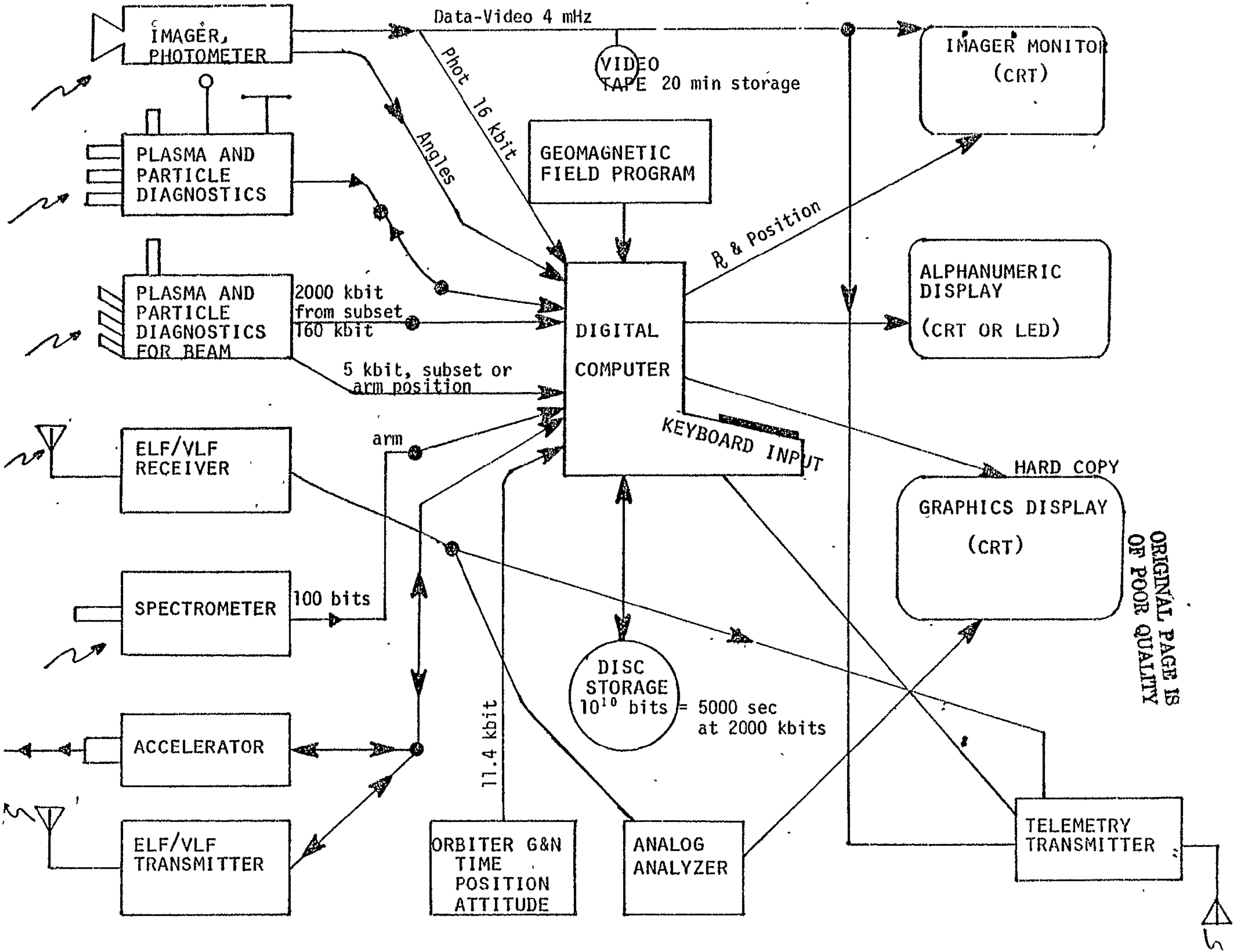

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